

## Tensile Properties of Textile Composites

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### Abstract

The importance of textile composite materials in aerospace structural applications has been gaining momentum in recent years. With a view to better understand the suitability of these materials in aerospace applications, an experimental program was undertaken to assess the mechanical properties of these materials. Specifically, the braided textile preforms were infiltrated with suitable polymeric matrices leading to the fabrication of composite test coupons. Evaluation of the tensile properties and the analyses of the results in the form of strength, moduli, Poisson's ratio, etc., for the braided composites are presented. Based on our past experience with the textile coupons, the fabrication techniques have been modified (by incorporating glass microballoons in the matrix and/or by stabilizing the braid angle along the length of the specimen with axial fibers) to achieve enhanced mechanical properties of the textile composites. This paper outlines the *preliminary* experimental results obtained from testing these composites.

### Introduction

The advantages in using the engineered laminated composites having high specific strength and specific modulus in the design of payload sensitive spacecraft have been known for some time. As the range of applications using these laminated composites is increasing, other design limiting problems such as the interlaminar strength, material toughness, fabrication and tooling costs need to be addressed critically. By virtue of the inherent geometrical layups of laminated composite structural components, non-uniform stresses in the various layers and directions take place under loads. These stresses in turn induce interlaminar shear and normal stresses at the 'free' boundaries or edges [1] of composite laminates resulting in damage and/or premature failures. While design modifications or techniques can be incorporated to suppress the delaminations, nevertheless newer approaches in developing alternate and cost-effective technologies are needed. As a result, the existing technologies from the textile industry are being explored and developed [2,3] in the design of aerospace composite components.

Many of the textile manufacturing processes such as braiding, knitting, and weaving will reinforce through the "thickness" of the composite structural components, thereby virtually eliminating or minimizing the effect of delaminations as well as giving rise to additional strength, if necessary, between the layers. Further, it's believed that the textile fabrication technologies could contribute to lower costs. As a result, the research and developmental activities in the use of textile technologies for structural composites are gaining momentum in developing multiaxial fabrics, integrally woven structures with stiffeners, and near-net-shape preforms [4,5]. These textiles preforms assume the near net structural shapes after impregnating and curing with suitable matrix with very little, if any, further processing operations. In addition, the textile preforms in their near-net-shape may be dry, prepregged or impregnated with (matrix) powder or commingled with matrix filaments. The latter two techniques by-pass the (liquid) resin transfer molding operation. One of the attractive features in using the net-shape preform technologies is its amenability for automation such as pultrusion, where production quantities justify, thereby maintaining quality control and lowering the cost of fabrication.

### **Materials, Processing, and Fabrication**

The graphite textile preforms were braided with tows of Celion G30-500 (BASF Structural Materials, Inc.) fibers. These fibers measure 7 microns in diameter and have a modulus of 30 Msi. The preforms were braided by a 4-step process where each tow was interlocked with the other tows to form a true 3-D structure. The braid angle was varied between 17 and 30 degrees.

The preforms were fabricated using a vacuum/compression molding consolidation process. The matrix system was comprised of two components-Epon 828 (Shell Chemical Co.) and Jeffamine T-403 (Texaco Chemical Co); 100 parts-by-weight to 42 parts-by-weight, respectively. This resin system was chosen because it had a relatively long pot life and low viscosity which was necessary for this method of molding. The two components were heated separately at 60° C for ten minutes to reduce the viscosity which in turn reduces the time required to evacuate the catalyzed resin. The two components were then combined and evacuated for ten minutes after the vacuum pressure reached one Torr. The bottom of the stainless steel mold cavity was completely covered to a depth of about 1/16" with the evacuated resin. The textile preform was then placed into the mold cavity and was covered with the remaining resin, and again evacuated for ten minutes after the vacuum pressure reached one Torr. Once the evacuation process was complete, the plunger was placed in the mold cavity and the mold was placed in a heated press where the excess resin was squeezed out in order to obtain a desired composite thickness. The nominal specimen dimensions are 0.100 x 0.750 x 10 inches. The composites were cured for three hours at 100° C. The fiber volume of the specimens was found to vary between 45% and 55%. The tensile coupons were tabbed using 1/8" fiberglass tabs. The tabs were attached with an adhesive film, FM123-5 (American Cyanamid), which required a cure cycle of 90 minutes at 100° C and

50 psi. The geometry and dimensions of four different types of braided test specimens are shown in Figure 1.

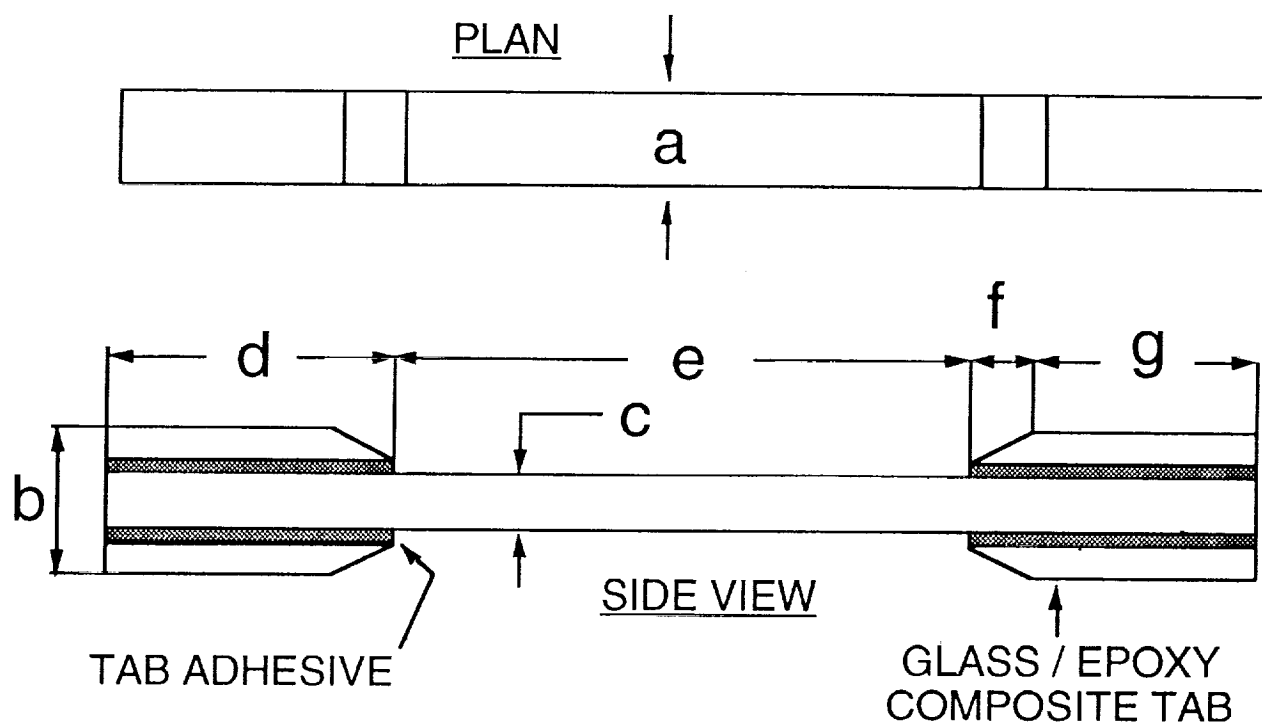
In an effort to lower the density of the composite specimens, glass microballoons were introduced into the matrix of some of the test coupons. Glass microballoons can be thought of as controlled voids which will displace some of the resin. Thus, the idea was to use controlled voids to reduce the density of the samples without any significant loss in many of the properties. The glass microballoons used in the study had a diameter range from 7 to 70 microns. The resulting density reduction was found to be about 2%. The specimen without microballoons had a density of  $1.51 \text{ g/cm}^3$  and with microballoons, it was  $1.48 \text{ g/cm}^3$ . The test results indicate that the resin displaced by the glass microballoons (5% by weight) did not significantly affect the tensile strength of the composite specimen. However, a difference in the strain behavior was observed. Further studies are suggested to optimize the strength and density with respect to the percentage of microballoons that can be incorporated in the composite materials.

## **Experimental Results and Analyses**

Numerous factors affect the performance of braided textile composites. It is not uncommon to observe significant variations in the mechanical properties of braided composites. At the laboratory coupon-level fabrication, the quality control of textile composites becomes even more critical if one is assessing the relative merits of these composites for their mechanical properties. Several factors such as the quality of braided preform, stabilizing the braid angle through the molding process, extent of curing, compaction of the preform, maintaining precise fiber volume ratio, size effect, uniform density, location of the specimen cut from a finite length of the preform, complete removal of voids and tiny pockets of trapped air bubbles, uniform distribution of fiber tows and the surrounding matrix throughout the length of the test specimen, symmetry of the composite, dimensional variations in the as-molded specimen, etc., may adversely affect the mechanical properties.

*Preliminary* experimental data of the tensile properties of four different types of braided composites are shown in Table I. In presenting this initial data, no attempt has yet been made to censor the data based on the factors mentioned in the preceding paragraph that may adversely affect the mechanical properties. Further analyses of the raw data are underway to refine and compare the properties of the four types of specimens with the factors that influence the results in the background.

The objective in introducing the glass microballoons in the composite was to not only lighten the braid but to reduce the formation of resin pockets that may develop at the crossings of large-sized (12k) tows. A cursory examination of the resulting data as shown appears to indicate that the nominal tensile properties were not affected except for the transverse strain. Based on density and fiber volume ratio measurements to be performed shortly, the eval-



### TYPICAL BRAIDED SPECIMEN GEOMETRY

#### TYPICAL DIMENSIONS OF FOUR TYPES OF SPECIMENS\*

	a	b	c	d	e	f	g
Plain braids	0.750	0.352	0.102	2.75	4.5	0.25	2.5
Braids with microballoons	0.753	0.354	0.104	2.75	4.5	0.25	2.5
Braids with axial fibers	0.877	0.354	0.104	2.75	4.5	0.25	2.5
Braids with axial fibers & microballoons	0.878	0.362	0.112	2.75	4.5	0.25	2.5

\* All dimensions in inches. Braids with axials have 37% (26 tows out of 70) axial fibers.

Figure 1. Tensile Specimen Geometry and Dimensions

TABLE-I : TENSILE PROPERTIES OF BRAIDS\*

	Braid angle (deg)	Load P <sub>max</sub> (kip)	Stress $\sigma_{max}$ (ksi)	Strain $\epsilon_{11max}$ (%)	Modulus E <sub>11</sub> (Msi)	Trans.Strain $\epsilon_{12}$ (%)	Poisson's ratio V <sub>12</sub>
Plain braids	23/30	13.22 ±1.7	173.5±23	1.47±0.09	11.8	2.31±0.36	1.57
Braids with microballoons	21/30	13.44±2.3	172.1±29	1.52±0.11	11.3	2.69±0.40	1.77
Braids with axial fibers	-	15.81±1.0	179.0±14	1.34±0.07	13.4	1.19±0.27	0.89
Braids with axial fibers & microballoons	-	13.14±2.3	135.3±27	1.26±0.10	10.7	1.39±0.33	1.10

- \* The experimental data shown here in tabular form is for convenience only. Comparison of data among the various cases shown here is not recommended. Extensive data reduction and detailed analyses are planned for the purpose of comparing the properties on a rational basis. Factors such as braid angle, fiber volume ratio, failure zones, size effect, density, specimen imperfections, if any, etc., are expected to influence the preliminary data shown above.

uation of specific mechanical properties will be conducted. If the succeeding analyses prove to be encouraging, a corollary that needs to be addressed is the percentage of microballoons that could be introduced in a unit volume of the braid resulting in one or more than one designated optimum property or properties. Further, what is the effect of introducing other grades of microballoons as to size and specimen thickness on these properties?

A nonuniform drift in the braid angle was noticed which may be attributed to the compression molding process. In order to stabilize the braid angle as well as to further improve the mechanical properties of the braids simultaneously, axial fibers(tows) were introduced during the preform fabrication. As expected, preliminary data reveal an improvement in the nominal tensile strength and modulus, and a decrease in the strains. The percentage of axial fibers selected in this study was random. Optimization techniques may be applied to determine the percent of axial fibers that can be embedded in braided specimens.

The experimental results with a matrix containing microballoons and braids containing axials were obtained very recently and are being analyzed critically to understand their significance.

## Conclusions

1. Four different types of braided specimens were studied to assess their tensile mechanical properties. Factors that affect the properties are identified for further data reduction and analyses.
2. A preliminary evaluation on the effect of microballoons in the plain braided composites on the mechanical properties is presented. Many of the properties appear to remain unchanged. Further analyses based on density measurements may show an improvement in some of the specific properties.
3. Axial fibers were introduced in the braids to improve the mechanical properties further, and the preliminary results are encouraging.
4. Through these studies, it has become clear that many factors affect the mechanical properties ranging from preform and composite fabrication through testing and rational data reduction.

## Acknowledgements

This work is supported by the National Aeronautics and Space Administration through a Grant Number NAGW-1331 to the Mars Mission Research Center at North Carolina State and North Carolina Agricultural and Technical State Universities. Prof. El-Shiekh, a member of the MMRC at NCSU, contributed the braided preforms.

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